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WATERSHEDS AS THE BASIC ECOSYSTEM: THIS CONCEPTUAL FRAMEWORK PROVIDES A BASIS FOR A NATURAL CLASSIFICATION SYSTEM[1]

Frederick B. Lotspeich[2]

ABSTRACT: A scheme is outlined to classify watersheds as ecosystems, based on their natural attributes. Two physical factors of the environment, climate and geology, are selected as state factors. Climate is the master factor that supplies energy and water to all ecosystems; geologic structure supplies the materal from which the forces of climate carve landforms to establish ecosystems. At the next lower level, soil and vegetation interact in a succession of transactions to produce a mosaic of tesseras within each watershed. It is these interacting tesseras that moderate climate and store energy within the ecosystem that influences the embedded stream. At the bottom of the scale is the stream with its passive role and inability to interact with the higher factors of the ecosystem. Thus, we have a controlling force consisting of two elements (climate and geology), a reacting force (soil and vegetation) that responds by circular conditioning to controlling forces, and at the lowest level, the stream which responds to all factors of the living system within its watershed.
(KEY TERMS: watersheds; ecosystem; classification; physioclimatic control; transactional factors.)

INTRODUCTION

Passage of the Clean Water Act in 1972 by the United States Congress placed all waters of the nation under federal jurisdiction – not just navigable waters as defined in previous laws. Section 208 of the Act addressed nonpoint sources (NPS) of water pollution, and by so doing, made all headwater streams and their watersheds subject to federal control. Because rational control of NPS can only be gained by suitable criteria, a tremendous task of stream assessment, to include their watersheds, is required to provide a basis for monitoring changes in stream quality as these watersheds are used for forestry, grazing, and agriculture, to name a few. A logical approach to the problem – every catchment cannot be studied individually – is to devise a universal watershed classification system that can be used by all resource managers because factors controlling watershed functioning are common to all regardless of users. Although the "Act" emphasized streams, implying humid regions, all parts of the nation, arid and humid, have drainage patterns that include watersheds, hence can fit into a system of watershed classification.

Most attempts to classify streams begin with the stream and describe many morphometric features in great detail; however, if they started with a properly classified watershed, morphometry would be superfluous. Platt's (1974) classification of streams of the Idaho batholith reflects a serious attempt to relate many features of the environment to the stream. However, this worthy effort would have been simpler and more useful had he started by establishing classes of causes instead of effects – this fundamental principle will be discussed later. There is no doubt that streams can be classified in a hierarchy of watershed types (ecosystems) that will permit them to appear in groups or classes, and thus simplify assessment of stream quality. Although our understanding of ecosystem functioning may be incomplete, we have sufficient knowledge of these entities so that, by judicious application, we can use them as production systems without exceeding their resiliancy limits.

THE ECOSYSTEM CONCEPT

Any classification of streams would be included in a classification of watersheds as ecosystems because they are the integrated product of the watershed. Therefore, the ecosystem will comprise the conceptual framework for the following discussion. Major (1969) points out that ecosystem is an ancillary concept in his scholarly treatment of its history. Early scholars had the insight to recognize the interrelationships of natural groupings of life and, although the names may be different, they all convey a functioning system controlled by interacting factors. Despite this early recognition, it was Tansley's lucid definition and description of what constitutes an ecological system that gave it the present wide acceptance. Tansley (1935) defined ecosystem as "a system resulting from the integration of all living and nonliving factors of the environment."

Although modern ecologists accept the ecosystem as a conceptual framework, the variety of definitions reflects the need or aspirations of the discipline wishing to apply the concept. Thus, plant ecologists look at vegetation, foresters at trees, range managers at grasslands, pedologists at soils, and aquatic biologists at streams. All agree that it is the entire environmental complex that forms the base for each objective,

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but they do not agree on the common denominator to describe their ecosystem.

Rowe (1960) urged that the ecosystem be adopted as the fundamental concept for describing, classifying, and integrating forests. Moreover, it was reiterated that ecosystems are geographical entities and they are not readily systematized without reference to the earth's surface. Krajina (1972) takes a similar view in describing the forests of British Columbia, although he stresses the biotic factors as opposed to the physical environment. This illustrates the point made earlier, that the entity being studied dominates most schemes when, in reality, it is the total system that should be the basis for classification.

Canada's ongoing land classification program views the ecosystem as productivity units with the natural landscape as the base for describing these units (Hills, 1961). Lewis (1969), in discussing range as an ecosystem, also cites the need for site classification to control ecosystem development and functioning. A frequently noted difficulty in studying ecosystems is the lack of discrete boundaries between adjacent ecosystems and the subunits within. Ecotones are usually diffuse with biological transition zones forming boundaries. Hill (1974) views the landscape as a mosaic formed by various combinations of interacting ecofactors to form ecosystems as "hazy wholes" without narrow boundaries. He designates each unit of the mosaic by "tessera" (something that is likened to a piece of a mosaic) which appear distinct when viewed from a distance but become "hazy wholes" when examined close up. Schultz (1969), in his discussion of the tundra as an ecosystem, also concluded that a major problem for ecologists was defining the boundaries of the systems under study. In developing a sound land use policy, we must use the ecosystem as the base for resolving the conflict between maximum protection and maximum yield (Odum, 1969). Moreover, we can no longer entertain the notion of one problem-one solution – but must replace it by some form of ecosystem analysis that considers man as a part of, not apart from, the environment. The watershed is a natural entity that permits fitting ecosystems into a hierarchy according to their natural characteristics and capability to produce as systems.

WATERSHEDS AS ECOSYSTEMS

Most ecologists consider watersheds, or catchment basins, as ecosystems with a range of complexities, depending on their size. Major (1969) writes "A watershed is an ecosystem subject to multiple use." Odum (1969) emphasizes that if water pollution problems are to be solved we must consider the entire catchment basin as an ecosystem. It is not just the water that is impacted by improper land use practices but the entire watershed system, whatever its size. Likens, *et al.* (1977), advocates the use of small watersheds as ecosystems to study nutrient cycling, hydrologic performance, geologic weathering, and other natural processes. The concept of watersheds as ecosystems is amplified by Cooper (1969) who writes that the definition of a watershed is nearly synonymous with the classic definition of an ecosystem, i.e., "a specific segment of the earth's surface, set off from adjacent segments by more or less discrete boundaries, and occupied by a particular group of plants and animals." As such, small watersheds can be studied as ecosystems and management practices developed, tested, and implemented through a theory of ecosystem interactions. Other ecologists view watersheds in a somewhat different light, not as discrete ecosystems, but simply how the water flows on the surface of the land (Cain, 1968). The problem of classifying natural areas, especially aquatic ecosystems, would be greatly simplified if the watershed were the base for classifying since it is the watershed, functioning in response to external forces, that controls aquatic systems.

The rationale supporting the concept that watersheds can be viewed as ecosystems is that they share many properties or characteristics that cause them to converge into a common system. They share common boundaries, which for watersheds are usually more easily defined than are those for the conceptual ecosystem. Most watersheds were formed by processes operating in their respective valleys in response to Playfairs Law (Strahler, 1975). Parallel to the watershed development, flora and fauna evolved in response to climate acting on a geologic unit. These continuous evolutionary changes, based on processes operating at present, reflect the principle of uniformitarianism, first expoused by Lyle, Hutton, and Playfair (Buol, *et al.*, 1973), i.e., the processes operating today are the key to the past. This concept does not imply that process rates have been continuous through time, there have been interruptions and replacement by other processes in response to climatic changes and orogeny of geologic structures. Both ecosystems and watersheds were shaped by climate consisting of energy and water. During the process of shaping watersheds, water provided kinetic and potential energy to detach, entrain, and carry away by erosion, the products of weathering. Solar radiation provided energy for life to evolve and form discrete units within individual watersheds.

Shapes of watersheds (physiographic form) are controlled primarily by geologic structure and processes; differences in processes reflect differences in climates (Hunt, 1974). The same can be said for soils which form contemporaneously with landscape. Vegetational units under a given macroclimate tend toward a common physiognomy (Daubenmire, 1968). Thus, forests evolved under a given set of climatic factors, grasslands in another, and deserts in still another. Although such factors as relief, orientation of mountain ranges with relation to prevailing air mass movement, and proximity to oceans are important considerations, these geographical relationships provide convincing evidence that macroclimate is a predominant environmental factor controlling the regional evolution of land forms.

Small watersheds, with their associated biota, are those of first order streams defined here as those "with sufficient continuous flow to support an aquatic biota at all seasons." These basins are headwater catchments for larger streams and tend to be, because of their size, more homogeneous in geology, soils, and vegetation that higher order watersheds. Watersheds and ecosystems are governed by the same forces. Watershed science focuses on the physical environment whereas ecosystem

sciences are usually associated with biological concerns. In reality, they can be thought of as subdivisions of a single science when the watershed is considered to be the ecosystem; hence, scientific hydrology might well be the unifying science linking biology of watersheds with their physical environment.

Meinzer (Katzmann, 1965) defined hydrology as the "science concerned with the occurrence of water in the earth, its physical and chemical reactions with the rest of the earth, and its relation to life on earth." A more elegant, succinct definition closely paralleling Meinzer's states "Hydrology is the study of the interrelationships and reactions between water and its environment in the hydrologic cycle" (USCSC, USGS, 1966). This last definition encompasses all aspects of earlier ones and implies an ecosystem that contains water, therefore including all of the earth's biosphere.

Watersheds have physiographic boundaries that prevent most interaction with adjacent watersheds except for migrations of certain mobile biotic populations and occasionally transfers of ground water along porous subsurface strata. Within such a basin, the ecosystem consists of streams, vegetation, soils, and associated biota, forming a mosaic of tesseras in response to local climates and physiography within the individual basin. These mosaics will tend to repeat in nearby basins of similar physical environment. The diversity of tesseras within a watershed increases as the watershed order increases, and watersheds become larger, the mosaics become more diverse as the range of environmental patterns enlarges. Streams flow as linear continuums and stream quality is the product of watersheds functioning as an ecosystem.

Hills (1974), in discussing ecosystem functioning, feels that the traditional concept of cause and effect should be discarded and the term "condition" be substituted; conditioning may be thought of as influencing, but not causal. Moreover, this conditioning produces circular resultants as various factors interact within the system. Mutually dependent interactions of the system are called transactions to emphasize their interdependency. Therefore, any change in the system must be attributed to the system interacting as a transactional whole. Some factor may be a major conditioning agent for change, but degree of conditioning is dependent on transactions within the system. Such conditioning may include man's influence when watersheds are used as production systems. An ecosystem in equilibrium has a homeostatic feedback mechanism that permits a range of resiliency in which it can be stressed without destroying its functioning. One important objective of ecosystem research is to define this range to facilitate enlightened management and thus avoid overstressing ecosystems used as production units.

Enlightened watershed management might well increase watershed productivity and diversity with man in symbiosis with the ecosystem. There is no evidence that the natural solution to environmental problems is necessarily the best (Dubos, 1973) or that man working with nature cannot generate ecosystems more diverse, interesting, and productive than those occurring in a state of wilderness. However, this can only occur when man's use and manipulations of the ecosystems are in harmony with the requirements, characteristics, and dynamic equilibrium of the system as a unit to include social and economic values. Present and past management practices remain based on facts about isolated populations, not a set of predictive statements about integrated systems. The level of ecological theory which holds great promise for the future that can effectively guide management is a theory of ecosystems processes (Cooper, 1969). To develop knowledge of ecosystem response to management practices, these systems, as watersheds, must be grouped by some natural classification scheme that groups them by classes.

A SCHEME FOR A UNIVERSAL WATERSHED CLASSIFICATION

An all-encompassing classification of land units that uses the ecosystem concept must be based on natural elements, not on the parochial concepts that have been used as guidelines in the past. Natural elements of such a scheme are those that have been, and are presently, functioning to produce and maintain viable ecosystems. The final product is intended to stress the potential of a natural segment of a landscape as a production unit and to manage it according to its capabilities to function as an ecosystem without destroying the resource base. In other words, it permits managing from knowledge – not ignorance, i.e., with man in harmonious symbiosis with nature. Basic to any such classification is the selection of "state" factors (those essential to, and which control, all biological-physical interactions within a system) (Lewis, 1969) that control all other interacting factors. Moreover, we must remember that landscapes are the products of past conditions which may be very different from the present and be prepared to accept, and adjust to, future changes in processes that may be catastrophic in nature. It is here that we should recall the principle of uniformitarianism that the present is the key to the past and Playfair's principle of valley development in response to universal natural laws.

STATE FACTORS

As a prelude to developing a scheme of watershed classification, it becomes imperative that the correct "state" factors be selected. During this selection the following principle should apply: "a fundamental principle of scientific classification is that the setting up of classes of things is better done according to the causes of the class differences than according to the effects that differences produce" (Strahler, 1975, p. 243). This principle will be the overriding guide in the following development of watershed hierarchy of classification from the region to the habitat type. Although the need for watershed classification evolved because of the need to describe stream systems, stream habitats cannot be adequately classified unless the entire system is considered as an integrated unit.

It is not the intent of this discussion to develop a classification system, but rather to outline the salient points that

must be weighed during the development of such a scheme. The classification must be based on natural criteria if it is to meet its objectives. One objective of ecological watershed classification is to classify habitats of a stream within a watershed class and compare its biotic potential with that of similar habitats of watershed classes within a region or between regions. The same classification scheme would also place watersheds in classes, based on their natural attributes, and thus permit their systems to be evaluated as production units. Geology and climate are the "state" factors that form the basis for classifying watersheds. Bailey (1977) uses these factors to develop his Ecoregion map, although he does not call them "state factors," his map and discussion could form a framework on which to develop a watershed classification scheme.

Geology gives each physiographic province its distinctive appearance. Within each province, geologic structure, acted on by processes controlled by climate, give shape to each land form. One set of geologic conditions under a specific climate will result in a certain land form, with its distinctive drainage pattern. Under the same climate but with a different geology the land form will be different. Similarly when lithology and structure (geology) remains constant, landforms developed under a humid climate will be distinctly different from those formed under an arid climate.

Bedrock geology upon which a watershed is developed is probably the most constant of all environmental factors influencing the character of a watershed. Although climate provides energy and water to establish and drive ecosystems, bedrock provides the materials from which landscapes are carved. Landscapes, as viewed today, are described as physiographic units fashioned by past and present geomorphic processes. Watersheds are products of these processes including chemical and physical weathering, and transport of erosion products to streams, which then transport these sediments to a point of deposition ultimately the oceans. All these processes, operating contemporaneously, require time, measured on a geologic scale, which provides ample opportunity for tthe establishment of adapted biota through evolutional succession.

Climate is the "state" factor that eclipses all other controls over watershed processes and must be considered as the master factor. Because climate is the overwhelming influence of all ecosystem features, it is imperative that suitable classes of climate be set up, ranging in scale from macro to microclimates. Microclimates include soil climate as envisioned and described by Buol, *et al.* (1973, p. 135), which can be of utmost importance as a control of environmental features. An example of this is the presence or absence of permafrost on north versus south facing slopes on the Caribou-Poker Creeks Research Watershed near Fairbanks, Alaska. Temperature measurements, taken at standard instrument heights, were nearly the same on both exposures; soil temperatures, however, revealed that the slope with permafrost had a temperature regime significantly different from that of the opposite slope (Lotspeich and Slaughter, 1979).

In describing climate, the concept of equivalent latitude should be considered. This is a way of equating latitude, azimuth or exposure to insolation, and slope angle to evaluate incoming energy under a variety of environments. Another potential tool that has not been used extensively and which should be evaluated, is the concept of "isophanes" as proposed by Horton (1938). Isophanes are lines of equal biological activity, as a function of temperature, which is in turn a function of latitude and elevation. Although all approaches should be explored, the simplest found to be adequate is most useful or appropriate. Daubenmire (1956) explained that by proper use of temperature and precipitation data derived from local weather stations, it is possible to define plant communities by discrete climatic regimens. Since it is a physiographic unit that constitutes a watershed, interacting with climate to produce a viable ecosystem, the next step is to describe and classify the "conditioning" effects of climate variations within an identified watershed.

TRANSACTIONAL FACTORS

Climate and geology (lithology and structure) are the principal elements of the physical environment that control the basic production unit and the integrated development of ecoclimate, soil, vegetation, and streams of a watershed. These four elements critical to all watershed life support systems are secondary factors in the functioning of the ecosystem because they are controlled by, and respond to, macroclimate and geology. Soil and vegetation, as conditioned by ecoclimate, are selected as transactional factors because they initially interact in such a way as to condition the development and productivity of the system.

Soil as a factor of the life support system is one part of the mosaic pattern of tesseras within each ecosystem. Although soil development is a function of five elements, climate, parent material, topography, time, and vegetation, only climate and parent material impart properties to a soil that are most important to watershed functioning and ecosystem productivity. Vegetation as a factor of soil development interacts within the constraints of local morphoclimatic factors giving specific properties to the soil. Conversely, the nature of the soil influences the vegetational complex of a watershed. Thus, an individual "tessera" composed of a viable plant association will usually have a specific soil type.

Soil texture, the pattern, distribution and size of soil particles within a soil profile, is probably the singl emost important property to ecosystem functioning. Soil texture is a property derived from the parent material through rock weathering and soil forming processes. Water relations of a soil, so important to terrestrial ecosystems, are determined almost exclusively by texture because of its influence on soil structure, an important factor controlling water relations. Further, they are controlling elements in surface runoff, infiltration and percolation to ground water, and susceptibility to erosion. Other soil properties, aggregation, organic-matter content, and ground cover also influence plant growth and water relationships but are secondary to texture and structure. Buol's, *et al.* (1973), treatment of pedology is a very

balanced approach to the subject of soil classification and is recommended reading for anyone interested in this aspect of soil science.

Some form of plant association constitutes the most visible element of a tessera within the mosaic of an ecosystem. Composition of plant communities reflect many variables that govern ecosystem functioning. Plants are influenced by macro- and micro-soil climate and by soil properties of chemistry, texture, and structure. An experienced scientist can deduce many watershed properties by observing plant communities. Distinctive plant associations may occupy opposite slopes of a watershed, and elevations within a basin strongly influence community structure. It is vegetation that makes watersheds productive units through their photosynthetic capabilities. Plants contribute to soil development through organic litter, root ramification within the soil mass, and nutrients released during decomposition. They influence watershed functioning by slowing runoff during storm events, by absorbing raindrop energy, and by producing a porous soil that absorbs water and slowly releases it to ground water.

Terrestrial vegetation has received deserved attention by plant ecologists and foresters who have devised various classification schemes to describe and organize vegetation into ecological units. Krajina (1972) developed a scheme for British Columbia that is based on the ecosystem concept. Krajina's concept makes no attempt to use the climato-physiographic interaction as the basic driving factors. Rather he insists that, since it is vegetation that he is classifying, he base his classes on biotic, not physical factors of the environment. Daubenmire (1956) also classes vegetation using the ecosystem concept and effectively separates his plant associations into climatic classes using temperature and precipitation data from local weather stations. Daubenmire makes more effective use of soil properties and stresses the transactional nature of soil and vegetation. He concludes that a natural system to meet the needs of climatologists, pedologists, and ecologists would permit all disciplines to recognize the same landscape divisions. Daubenmire treats, in a balanced manner, the subject of the ecosystem concept for plant classification that should lead to a natural system. Since more landscapes are now covered with successional vegetation, not climatic climaxes, he suggests that it would be more realistic to class vegetation by biotic potential through the use of habitat type than to resort to potential vegetation. Daubenmire's (1968) and Hills' (1960,1976) approach to classifying natural ecosystems are similar and both may provide keys when setting up a system of watershed classification.

Geomorophologists, working with watershed scientists, have devised many substantive approaches to describe, in quantitative terms, the many features of a watershed. Some of those can aid ecologists in relating tesseras of a watershed mosaic to landscape features such as soil and vegetation that would not be apparent in their absence. Some measurements may be made from high altitude photo or satellite imagery with a minimum of ground checking; others may be obtained from topographic maps. All can be combined into a computerized printout to amass landscape data and match it to ecological observations. Such treatments are especially pertinent to show how streams and their habitat types fit into the terrestrial ecosystem.

THE STREAM AS A FINAL INTEGRATED UNIT

Finally, to reach the crux of this discussion, I consider the stream embedded in the watershed to be the integrated result of the previously discussed factors of ecosystem processes. A scheme to classify streams would facilitate their assessment as they respond to nonpoint sources of pollution as various management practices are applied to their watersheds.

Streams are the production units of watersheds that transport water and are the sites for aquatic life. Although streams are the integrated product of all factors of their watershed, theirs is a passive role in the day-to-day functioning of the system. Unlike transactions between soil and vegetation, streams systems can only respond to interactions of the ecosystem within the watershed. Stream flow rises and falls in response to rainfall; and any perturbation affecting the tesseras of the watershed is reflected by the stream. However, it has a very limited influence on interactions originating outside its banks; in other words it does not participate fully in the transactional nature of watersheds functioning as ecosystems.

How does a watershed influence its streams? Obviously a watershed, or a catchment basin, collects precipitation that falls on the surface and directs a portion of this water to the stream by surface runoff and ground water flow. Soils and vegetation influence the rate at which water reaches a stream under a given intensity of storm event. The degree of weathering of bedrock and soil development in the weathered products influences the capacity of the soil to absorb and store water. Lithology determines soil texture which in turn controls soil water storage capacity for plant communities. Geologic structure has a strong influence on morphology of a given watershed and its slope stability and steepness which, in turn, controls processes of erosion, leaching, and ultimately the potential productivity of the site. Orientation with respect to prevailing winds and snow accumulation influences flow stability. Time is a factor in rock weathering and the stage of erosional cycle that controls valley wall steepness and stream gradient. Lithology has the strongest influence, followed by the integrating influence of the vegetation-soil complex.

The nature of the stream substrate is strongly influenced by lithology of the landscape and stage of the erosional cycle. Both of these control texture of the substrate, whether gradients are steep to give chute-like flows, or whether a more gentle gradient will prevail to give a riffle-pool sequence. All these factors must be considered when classifying stream systems and the habitats that support aquatic life. This scenario illustrates how an understanding of the total environmental and biotic structure and functioning of watershed simplifies stream classification. Only a relatively few parameters need to be measured if the watershed is properly classified because the stream is the final visible, integrated product of its watershed ecosystem. Figure 1 is a graphic summary of the preceding

discussion from the regional physiographic unit to stream habitats with increasing detail as scale decreases.

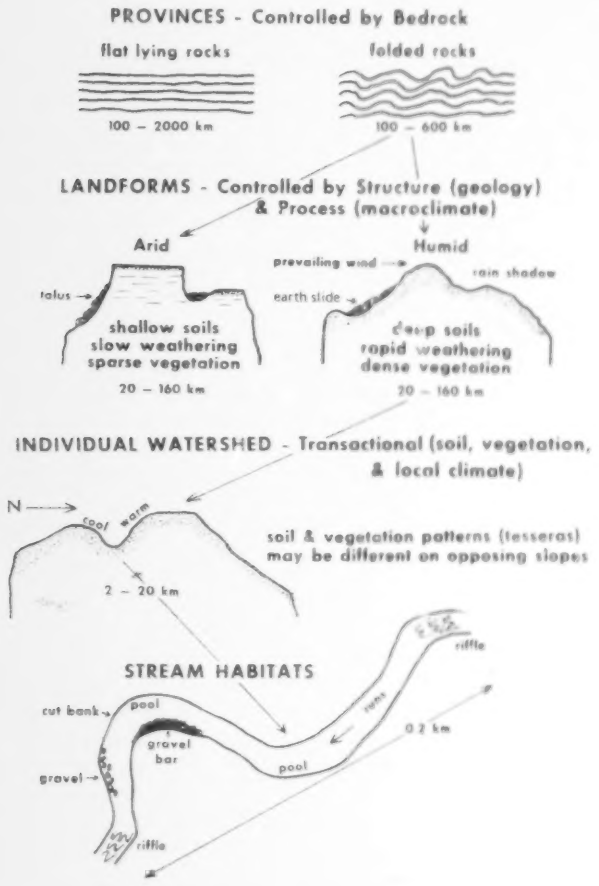

Figure 1. This Diagram Illustrates How Geology and Climate Control Landforms From Continental, Through Geomorphic Provinces, to Individual Watersheds, and Finally to the Stream Habitat.

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